Headquarters U.S. Air Force

Integrity - Service - Excellence

Phytoremediation Basics (Protocols)

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Topics Covered

- **Definitions**
- **Requirements for success**
- **Potential problems**
- **Advantages/disadvantages**
- **Examples**
- **Sources of information**
- **Summary**

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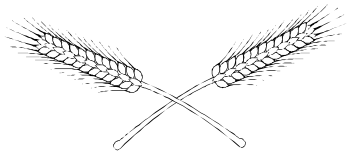
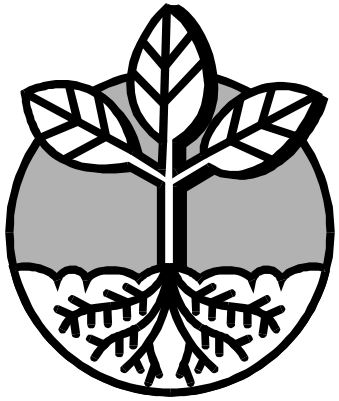
Phytoremediation

- **Phytoremediation is the direct use of living plants for *in situ* remediation of contaminated soil, sludges, sediments, and groundwater through**
  - **Contaminant removal**
  - **Degradation**
  - **Containment**



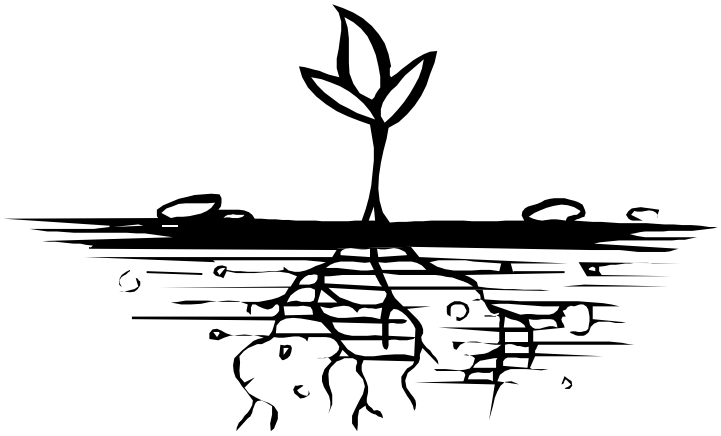


Adapted from: "U. S. EPA, 1999. *Phytoremediation Resource Guide*. Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, DC; EPA 542-B-99-003 http://www.clu-in.org/pub1.htm

Terminology

- **Phyto – *plant* or to grow**
- **Rhizo – *root*, also contact with roots**

- **Key phrases or words**
  - **Direct use of living plants**
  - **Remediation**
  - **Contaminant**
    - **Removal**
    - **Degradation**
    - **Containment**



Sub-fields of Phytoremediation*

Phyto*stabilization*

Phyto*extraction*

Phyto*degradation*

Phyto*volatilization*

Rhizo*filtration*

Rhizo*degradation*

- **Vegetated landfill covers not a sub-field because**
  - **Cover normally does not interact with contaminants**
  - **Cover controls water, gas or access to waste**

*Complete definition in AFCEE publication: *Draft Protocol for Controlling Contaminated Groundwater by Phytostabilization*. November 1999

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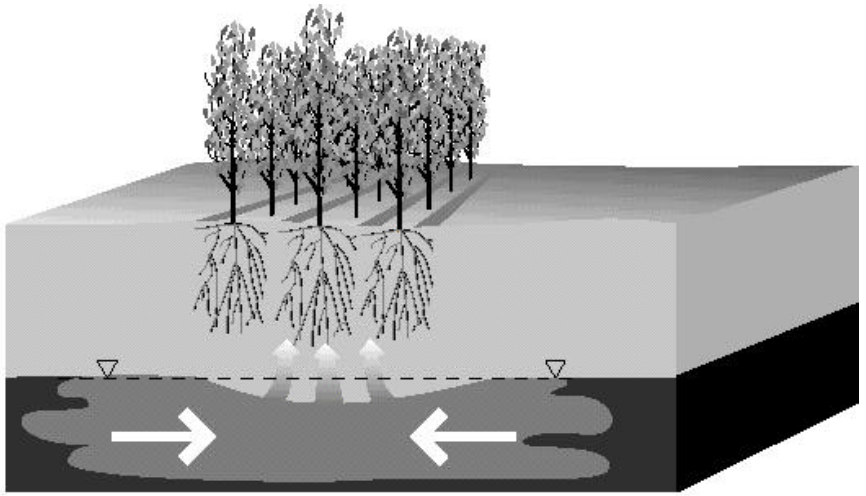
Phytostabilization

- Immobilize contaminants by
  - Absorption and accumulation by roots
  - Adsorption on surface of roots
  - Precipitation of chemicals in the root zone
  - Removing groundwater in order to control groundwater movement



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Phytoextraction

Also called phytoaccumulation

- **Contaminants enter the plant through roots and accumulate within the plant**
  - **Hyperaccumulators absorb large amounts of metals or other contaminants**
  - **Plant material is harvested then incinerated or composted; the residue is disposed of**

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Rhizofiltration

- **Roots in hydroponic culture**
  - **Contaminated solution surrounds the roots**
- **Contaminant adsorbed or precipitated onto roots or absorbed into the roots**
- **Plant parts harvested then incinerated or composted to destroy or recycle the contaminants**

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Phytodegradation

Also called phytotransformation

- **Contaminants broken down by metabolic process within the plant**
- **Contaminants broken down (externally) by compounds (e.g., enzymes) produced by the plant**
- **By-products may be incorporated into plant tissue and/or used by the plant as nutrients**

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Rhizodegradation

Also called enhanced rhizosphere biodegradation, phytostimulation, or plant-assisted bioremediation/degradation

- **Occurs in the root zone or rhizosphere**
- **Natural substances released by roots**
  - **Sugars, alcohols, acids – containing organic carbon**
  - **Organic carbon is food for**
    - **Yeast**
    - **Fungi**
    - **Bacteria**
- **Microorganisms degrade contaminants in addition to consuming the natural organic carbon**

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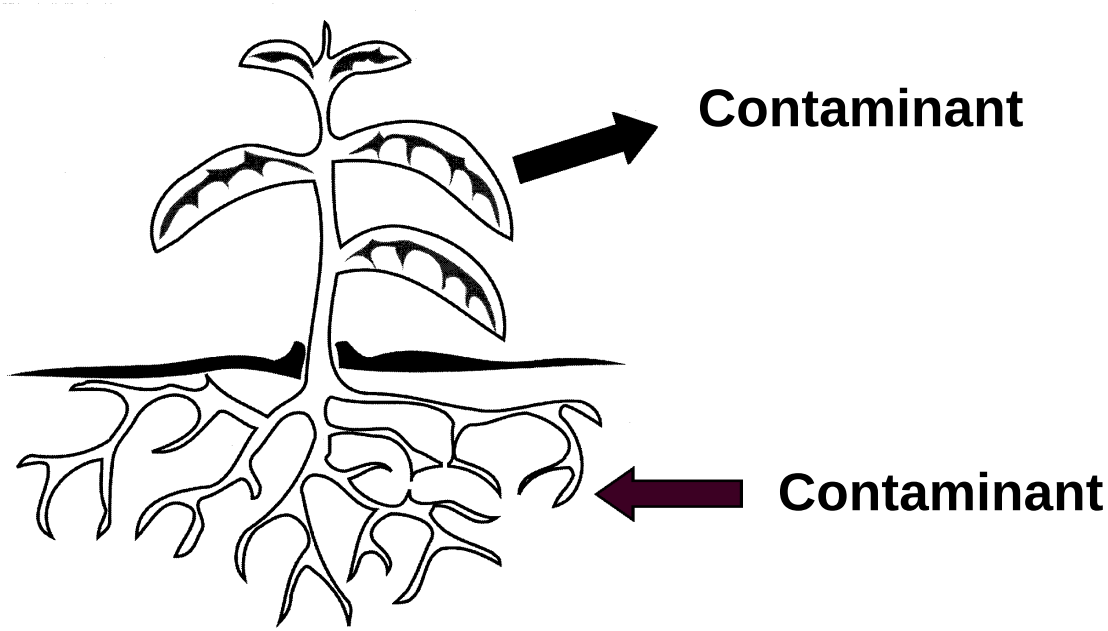
Phytovolatilization

- **Contaminant taken up by the plant and released as vapor into the atmosphere**
- **Contaminant may be modified within the plant**



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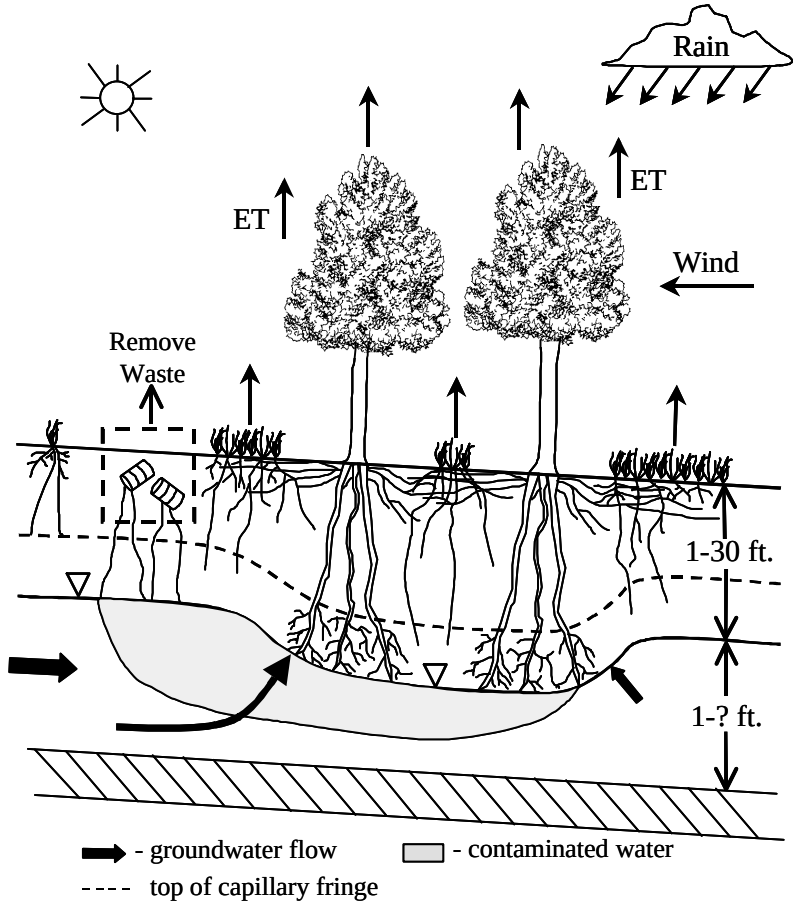
A Phytostabilization Site



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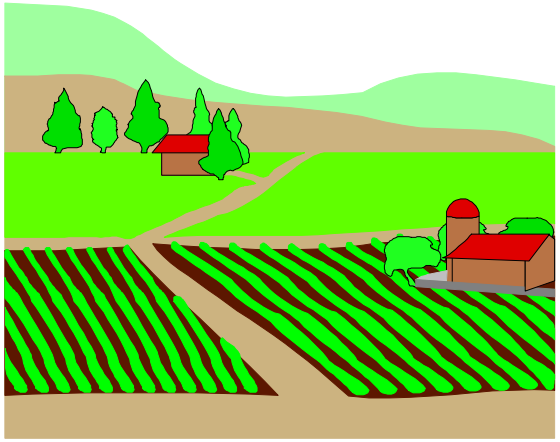
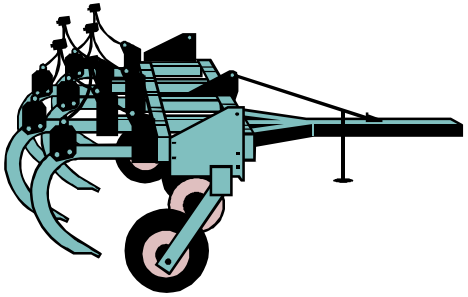
Requirements for Success

- Contaminant should be near the surface
- A plant must be available that can remediate the contaminant
- The plant(s) used should be adapted to the site
- The soil should support robust plant growth
- There should be adequate space in which to grow plants



Requirements for Success, (concluded)

- **Agricultural technology, machinery for planting and harvesting, and irrigation, if required, must be adequate and available**
- ***Remember – This is a farming or forestry operation***



Potential Problems

- **Potential and actual evapotranspiration may be too small to support success at the site**
- **Industrial sites on Air Force bases often have severely compacted soils that may limit plant growth**
- **Successful design, planting, and implementation requires extensive knowledge of agriculture (plants, soil, machinery, pest control, etc.)**
- **May require institutional controls**

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Advantages of Phytoremediation

- **Accepted by an informed public**
- **Potential for low cost**
- **May work well at low-risk sites**
- **May be used to complete remediation after initial cleanup to low but still unacceptable levels**
- **May operate with limited maintenance for decades**

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Disadvantages of Phytoremediation

- **May require large expense for relocating operations, buildings, roads, etc. at operating bases**
- **Slow plant establishment may limit application**
- **Requires much space because solar energy drives the engine and it is a low-density energy source**
- **Regulators may be unfamiliar with phytoremediation**
- **Usually ineffective during the plant's dormant season**
- **May be less effective with short growing seasons**

Example: Metal Hyperaccumulation

- **Number of suitable plants***

Metal	No. Plants
Cadmium	1
Cobalt	28
Copper	37
Lead	14
Nickel	317

* Baker, Alan J. M. Phytoremediation presentation at conference, Omni Hotel, Houston, June 1998

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Example: Remediation of Waste Pit

- One-acre waste impoundment, Houston, TX
- In use from late 1940s until early 1980s
- Disposed river silt and polycyclic aromatic hydrocarbons (PAHs)
- Natural invasion of plants 1980s to tests in 1996

Chemical	1 ft., mg/kg	2 ft., mg/kg	Sludge, mg/kg
Naphthalene	38	536	6813
Anthracene	66	113	856
Dibenzo Anthracene	0	0	5

Data by T. Wong in proceedings of Phytoremediation conference, Houston, June 1998. Remedial Technology Development Forum, US EPA

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Resources

- **Draft Protocol for Controlling Contaminated Groundwater by Phytostabilization – Air Force Center for Environmental Excellence (AFCEE) at *http://www.afcee.brooks.af.mil/er/ert/erthome.htm***
- **Additional resources located on the handout page in conference proceedings.**

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Summary

- Phytoremediation is a promising technology
- The science, engineering, and technology needed for routine use are under development
- Some individuals have overstated the potential
- Advantages
  - Cost-effective with low maintenance costs
  - Effective against low concentrations of contaminants over large areas
  - Highly acceptable to the public
  - “Natural system”